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SCIENCE AND TECHNOLOGY IN SPACE DURING THE COMING DECADE

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ABSTRACT

Scientific activities in space during the next decade and beyond will occur within the enabling framework of space technology. At the current stage of development, space technology is strongly dependent on the ability to deliver relatively large quantities of mass to useful locations in space, and to then assemble it. The scales and directions in which these mass delivery and assembly capabilities develop will depend critically into the foreseeable future on whether and how the American Strategic Defense Initiative (SDI) proceeds, and may in turn impact how the SDI can and will evolve.

INTRODUCTION

With respect to all activities in space, Arthur Kantrowitz has very aptly noted that we have recently been living in an Age of Timidity, one in which "our doubts are traitors, and make us fail, by fearing to attempt." At the moment, we seem to be at a nexus; whether the West will plunge further into self-doubt and continue its retreat from the frontiers or whether at least America will regain the cultural exuberance and technological optimism of two decades ago presently quivers on the hinge of fate.

In the following, it will be assumed that the American enterprise in space will *not* retrace the superficially inexplicable decline and extinction of the Ming Dynasty's Navy, that instead America will harken to the "better angels of its nature," and that what we are clearly physically and economically capable of doing in space during the coming decade will serve as a useful forecast of what we will actually accomplish in this pivotal endeavor. This rosy scenario is by no means assured, but the alternative is remarkably uninteresting to contemplate.

It seems appropriate in this survey to first review what will be technologically feasible in space during the coming decade, and then to consider a few examples of the science which can be accomplished within this technological framework.

SPACE TECHNOLOGY

Essentially all possible activities in space depend on projecting mass and energy into the space environment. At the present time, the cost of putting mass into space is lower-bounded by the Shuttle price of about \$1000/lb, which is about 10,000 times higher than the cost of the energy (as electricity at the Earth's surface) required to gain low Earth orbit. It appears both necessary and sufficient that the cost-to-orbit be reduced by at least ten-fold to ~ \$100/lb—that is, to no more than 1,000 times the associated energy cost—if really large-scale human activities are to commence in space.

A probable driver of such cost reductions is the Strategic Defense Initiative. Platforms in space—for surveillance, for energy generation, relaying and projection, for mass-launching, and for communications and battle-management—may be extremely high-leverage items for performance of the strategic defense mission. For them to exist and function under wartime conditions—and they are worse than useless unless they can reliably do so—they must survive whatever may be thrown at them by a capable and determined attacker. The only presently discernable way in which this is likely of success for even quite limited durations involves clever use of massive armor surrounding the orbiting platforms; such armor may defeat determined attacks by kinetic energy, particle and laser beams, at least for usefully long periods.

It is instructive to consider the mass scales of such armor. The types of orbiting space battle stations presently being seriously studied in the Strategic Defense Initiative have characteristic size scales of several tens of meters; the armor surrounding them therefore will typically have areas of the order of 10,000 square meters—a hectare. In order to be even transiently effective against credible threats, this armor will have to be of the order of 100 grams/cm^2 thick, not much less than that of a tank or a battleship. The mass budget of a major orbiting strategic defense platform will therefore have to include an allowance of the order of 10,000 tons for armor, and 100 such platforms—a characteristic size for strategic defense battle station constellations currently under consideration—will require a total of a megaton of armor.

At Shuttle costs—$2-3 million per ton lifted into low Earth orbit—a few trillion dollars will be required merely to put the required armor on the lower threshold of space. Thus, the SDI, if it is to pursue realistically its presently favored approaches to space battle stations, has an interest completely dwarfing all others in attaining *at least* an order-of-magnitude reduction in the cost of putting large amounts of mass into low Earth orbit. (Shuttle-derived rocket-based technology may ultimately provide such advances—with very little margin for shortfalls—but only at great costs in time and resources.)

A notable—and by no means exclusive—example of a near-term technology which offers to readily accomplish this is laser propulsion, along the lines first suggested by Kantrowitz. In this scheme, a high-average-power ground-based laser directs its energy onto a suitable aperture in the engine section of an ascending rocket, heating on-board reaction mass to far more energy-intensive conditions than can be attained in chemical reactions. The associated three-fold gain in exhaust velocity of the laser-energized rocket, relative to ordinary chemical rockets, permits small car-sized rockets to attain orbit with payloads masses of about half of their Earth take-off mass. As originally proposed, this laser-powered "railroad into space" used at most a few ground-based lasers; if it were augmented with a few relay mirrors, either in orbit or thrown up every few hours on the "laser railroad" itself, the efficiency of the railroad could be considerably augmented, and its operation extended into all of cislunar space, instead of just the fraction of the sky decently above the horizon of the ground-based laser(s).

The cost to put mass into orbit with such a laser railroad appears to be a few percent of current Shuttle costs—about $30/lb. A 1 gigawatt laser system on the Earth's surface, requiring of the order of 10 gigawatts of electrical energy to power it, could loft 15-20 tons per hour of *payload* into orbit, continuously—half to two-thirds of a Shuttle launch per hour, hour after hour. The electricity bill for continuous operation of this capability—which seems likely to dominate its costs—would be about $25 billion annually (plus or minus a factor of two, depending on how efficient ground-based lasers could be used). If low-cost base-load electricity could be bought at marginal production costs late at night from a nuclear reactor-rich U.S. power grid, the railroad's hourly operating costs would be 2-3-fold lower still (over about a third of the year). The annual tonnage hauled into low Earth orbit with continuous operation of this "laser railroad" would be about 150,000 tons, or about a sixth of the total SDI armor requirement annually.

What is uniquely important about this particular means of lofting SDI equipment into space at affordable costs is that it continuously exercises—in essentially full-scale—a capability to destroy an all-out strategic attack on the United States. The required laser system is of the average power level needed to destroy hundreds of ballistic missiles—or bombers or cruise missiles—every minute, and the pointing and tracking accuracies of the laser beam(s), aimed either directly or via relay mirrors, at ports on ascending engines on the laser railroad are closely comparable to those needed to effect strategic platform destruction, moreover over ranges from lasers to rockets which are immediately relevant to strategic defense applications. The operation of this laser railroad system thus would be a continuous and compelling—albeit manifestly peaceful—demonstration to all interested parties that the United States had in hand and ready for immediate use a formidable capability to destroy hostile air- and spacecraft, world-wide, at rates and under other conditions characteristic of all-out strategic war, one requiring only a C^3 sub-system to complete it.

It is also interesting to note that there are beneficient ends to be served by such a comparatively huge weight-lifting capability—in the event that you believe that removing the nuclear Damoclean sword from over the collective head of mankind is insufficiently beneficient. A teragram—a million tons—of high-quality metal (e.g., aluminum) in Earth orbit is a characteristic quantity for enhancing the global climate and the overall habitability of the Earth to extents of which mankind has only dreamed. Fashioned into maximally efficient orbiting shades and reflectors for sunlight, this megaton of metal deployed into 10 billion hectares of shade/reflector can be used to change the average solar illumination of the Earth by two-fold, much more than the difference between a completely ice-sheathed and an all-tropical desert Earth. (Specialized into frequency-selective reflectors of particular spectral bands of the solar spectrum, some such reflectors might serve, for instance, as illumination augmentors of cold territories which didn't perturb the local climate or, conversely, as air or terrain heaters which didn't disturb the diurnal illumination cycle.)

Properly steered "strings" and "lattices" of hundred-kilometer-scale orbiting reflectors and shades can be used to steer storm systems over deserts and there wring them of their moisture, while attenuating the soil-destroying precipitation intensity of tropical storms; marginal croplands can be warmed and illuminated into full fruition, while the life-sapping irradiance levels of the huge tropical deserts (e.g., the Sahara) can be moderated to levels supportive of human civilization. Most of the six-sevenths of the land area of our mother planet which now is effectively uninhabitable can thereby be reclaimed for humanity. We can thereby demonstrate our racial competence for terraforming other planets for human use by first bringing our own one to its full potential. It is striking that the cost is at most $100 billion to insert into orbit the mass needed for this project on which human history will turn, that is can be done with technology which already has been conceptually proven, and that it can be seriously commenced during the coming decade.

The "laser railroad" is by no means the least expensive means by which mass can be delivered in large quantities into cislunar space during the coming decade, however. It seems quite likely that electrical energy can be used on the surface of the Earth to accelerate matter to orbital speeds with efficiencies of well over 50%, with quite low unit capital costs, using integrated sets of existing technologies. Notable examples of these sets include "electromagnetic cannons" ejecting 100 kg-scale payloads at 10 km/second speeds from km-length, terawatt peak power level accelerators at ground level, and high tech squirt guns consisting of very high power density magnetohydrodynamic motors operating at continuous power levels approaching a gigawatt and ejecting continuous mm-diameter streams of metal at ~10 km/second speeds. Both of these options involve novel large-scale mass transport through the Earth's atmosphere at hypersonic speeds, which appears to be feasible. Each offers the prospect of lofting the characteristic megaton of metal into cislunar space at a total cost under $10 billion, albeit with far higher accelerations than those of the human passenger-rated "laser railroad."

The nuclear options—e.g., NERVA and Orion—of large-scale mass transport in space continue to be technically promising. However, the non-rational institutional constraints on the exercising of these options appear to be as formidable as ever, effectively precluding their serious consideration in the coming decade.

It is almost unnecessary to remark that lofting of matter of desired composition into specified orbits in necessary quantities is usually just a prelude to its becoming human-useful, for strategic defense, for climate enhancement, or whatever. With the possible exception of that arriving on the low-gee "laser railroad," the mass when delivered is unlikely to have the structure, the topology, the geometry of ultimate applications interest. It will be necessary to form and condition it, once it has arrived in space. Space assembly operations, probably working on length scales quite unprecedented in the history of human endeavor, will apparently be required.

It is currently fashionable to think of these space assembly operations as growing up around the Space Station, but it isn't entirely clear that at least some of them wouldn't be applications-dedicated and autonomous by the mid-'90s. Suppose, as a not entirely hypothetical example, that a commercial enterprise wished to establish a microgravity laboratory in low Earth orbit in the early '90s for conducting value-addition to certain pharmaceuticals or semiconductors, and moreover placed a very high value on maintenance of trade secrets and practices. If this enterprise were to attempt to contract with NASA to put a 5 ton module, including a two-person semi-permanent crew, into orbit in 1993, to be supplied and extended thereafter via its proprietary ground-based projectile launch facility, what would be NASA's response?

SPACE SCIENCE

One of the most enthralling things about scientific research is its intrinsic unknowability, even in the quite near term. In an environment as unfamiliar as space, even the outlines of the results of scientific endeavors as near as a decade hence are difficult to discern. Instead, consider examples of some of the types of scientific activities which seem particularly likely to be fruitful.

One of the most exciting scientific uses of burgeoning human access to cislunar space during the next decade may well be ultra-long baseline interferometric astronomy, extended into two dimensions and to far shorter wavelength (e.g., infrared through x-rays) portions of the electromagnetic spectrum. The pan-spectral "seeing" and the gigameter scale lengths available for NAVSTAR-exploiting detector "strings" and "lattices" within the Earth-Moon system will surely revolutionize astronomy to intellectual depths and breadths not seen since the initial availability of the telescope itself, as we begin to see kilometer-scale events at the center of the Galaxy, and objects the size of the Earth-Moon system at the edge of the Universe.

The huge aperture, extremely high quality orbiting optical instruments which are presently bidding to play key roles in strategic defense will surely have immediate spin-offs into more classical astronomical endeavors. Planetary astronomy in particular seems likely to advance discontinuously, as it becomes possible to study sub-kilometer size objects on the surfaces of Mercury and Mars, and single storm systems in the atmospheres of Venus, Jupiter and Saturn. The energy-projection capabilities of these super-telescopes may even permit spectroscopic analysis of the (surface) composition of solar system objects passing near the Earth-Moon system.

Micro-gravity electrophoresis presently appears as one of the ultimate techniques for separation and consequent analysis of exotic biological compounds. The combined exploitation of the micro-gravity and ultra-high vacuum of unsurpassed pumping rates of cislunar space may prove to offer far higher composition resolution of even very high molecular weight biological and pharmaceutical materials than can be attained with state-of-the-art microgravity electrophoretic techniques. This can be accomplished, for example, by cleverly forming beams of such molecules and then perturbing these beams gently with selectively resonant radiation over the uniquely long "drift-tubes" afforded by the space environment, prior to collection of the now-separated material.

Since microgravity electrophoresis is even now moving from a research tool to a commercial enterprise, it doesn't seem unrealistic to expect that substantially more advanced and far more sensitive techniques will be used in at least research efforts during the coming decade. Inasmuch as analytic and diagnostic capabilities traditionally have paced much of scientific advance, it may well be that the creative use of the space environment will become crucial for the timely advance of the "new biology" by 1995.

Epitaxial growth of even very large areas of complex structures, e.g., very high efficiency photovoltaics or ultra-high-speed transistors which cannot be realized with reasonable yield in Earth-based laboratories, is another notable prospect for near-term realization in orbital laboratories. It is remarkable that current human technology is essentially incapable of making structures less than about 10,000 atoms in minimum dimension, let alone exploiting such structures; most all of our playthings have rough composition uniformity over the (relatively narrow) range of a million to a billion atoms in minimum dimension. What technical advances will result from a genuine ability to design and implement structures of assuredly uniform composition which are dozens to thousands of atoms in minimum dimension we can only dimly perceive. Utilization of the space environment during the next decade may permit commencement of serious exploration of this utterly virgin scientific and technological territory.

CONCLUSIONS

The basic pace of human activities in space during the coming decade will quite clearly depend on whether and on what scale the Strategic Defense Initiative proceeds, particularly in the '90s. While it may be regrettable that one of the seminal developments in human history is so tightly interwoven with our racial proclivity to mass homicide, it is hardly unprecedented. During the past quarter century, we humans have learned to use space as a devastatingly effective medium through which to conduct attacks aimed at extinguishing mighty civilizations in a single hour. In the next quarter-century's course of forestalling such attacks from space on our homes and our people, we may rather inadvertantly lay the foundations of the first non-terrestrial human civilization. Out of dire peril may arise not only safety but entirely new environments for human development and expression.

All these, however, are still threads being drawn into history's loom. What is clear even now is that the existing technology base for moving large-scale human endeavors into cislunar space during the next decade is remarkably broad. The impact that some of these endeavors may have on the outlook for the human condition on Earth is strikingly large, in science and technology as well as concerning the survival of Western civilization.

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WHITHER THE SPACE ENTERPRISE?

- THE MING NAVY TRACK
- THE APOLLO PROJECT TRACK
- POSTULATE THE APOLLO PROJECT TRACK
- TECHNOLOGICAL FEASIBILITY FRAMES SCIENTIFIC OPTIONS

SPACE TECHNOLOGY

- STRONGLY DRIVEN BY MASS LAUNCH COSTS
  - SHUTTLE COSTS OF ~$1,000/LB.
  - 10,000 TIMES THE COST OF THE REQUIRED ENERGY (AS ELECTRICITY ON THE GROUND)
  - AT LEAST 10-FOLD COST REDUCTION REQUIRED FOR LARGE-SCALE ACTIVITIES
- POSSIBLE STRATEGIC DEFENSE INITIATIVE MASS LAUNCH REQUIREMENTS
  - SPACE BATTLE STATION ARMOR
    - ROUGHLY 10,000 TONS PER STATION
    - ROUGHLY 100 STATIONS
  - AGGREGATE REQUIREMENTS OF A MILLION TONS
  - SHUTTLE-BASED COST OF FEW TRILLION DOLLARS
  - SDI THUS MAY REQUIRE AT LEAST TEN-FOLD REDUCTION IN MASS LAUNCH COSTS

LASER RAILROADING

- NON-EXCLUSIVE EXAMPLE OF DRASTIC LAUNCH COST REDUCTION
- GROUND-BASED LASER-ENERGIZED SMALL ROCKET
  - HALF OF TAKE-OFF MASS IS ORBITED PAYLOAD
  - PAYLOAD COST-TO-ORBIT IS ROUGHLY $30/LB.
  - 1 GIGAWATT LASER ORBITS 150,000 TONS/YEAR
    - 5,000 SHUTTLE LOADS-EQUIVALENT
    - $10-25 BILLION ANNUAL OPERATING COST
- FULL-SCALE STRATEGIC DEFENSE CAPABILITY
  - COMPELLINGLY PLAUSIBLE
  - CONTINUOUSLY AND PEACEFULLY DEMONSTRATED
  - REQUIRES ONLY C^3 SUB-SYSTEM

SIDE-EFFECTS OF STRATEGIC DEFENSE
WEIGHT-LIFTING

- THE SIGNIFICANCE OF A MEGATON OF SPACE MATERIAL
- ORBITING SOLAR SHADES AND REFLECTORS
  - ONE MEGATON = 10 BILLION HECTARES
    - OPTIMALLY DEPLOYED, HIGH-QUALITY METAL
  - CHANGE SOLAR ILLUMINATION OF EARTH BY AVERAGE OF TWO-FOLD
    - OVER SMALL DISTANCES, E.G., 100 KILOMETER-SIZED PATCHES
    - OVER SHORT (SUB-DAY) TIME-SCALES
    - IN FREQUENCY-DEPENDENT FASHIONS, E.G.,
      - LIGHT-WITHOUT-HEAT
      - HEAT-WITHOUT-LIGHT
      - GROUND- OR AIR-HEATING
- CLIMATE ENHANCEMENT APPLICATIONS, E.G.,
  - BLOOMING DESERTS
  - MARGINAL AGRICULTURAL AREAS STABILIZED
- PRESENTLY UNINHABITABLE SIX-SEVENTHS OF EARTH'S LAND AREA 'HUMANIZED'
- COST UPPER-BOUNDED AT ROUGHLY $100 BILLION

OTHER WEIGHT-LIFTING OPTIONS

- GROUND-BASED, ELECTRICALLY OPERATED
  - HIGH ELECTRICAL EFFICIENCY, LOW CAPITAL AND OPERATING COSTS
  - ELECTROMAGNETIC CANNONS
    - LAUNCH STREAM OF 100 KG-SIZE PROJECTILES ENCLOSING PAYLOAD
  - MHD 'SQUIRT GUNS'
    - EJECT MM-DIAMETER STREAM OF ~10 KM/SECOND METAL, CONTINUOUSLY
  - ORBITED MEGATON FOR ~$10 BILLION COST
- NUCLEAR—NERVA AND ORION
  - BLOCKED BY CONTINUING NON-RATIONALITY
- SPACE ASSEMBLY TECHNOLOGY
  - PROBABLY REQUIRED FOR HIGH-GEE-DELIVERED PAYLOADS
  - UNPRECEDENTED IN SIZE SCALE
  - ACTIVITY SITES UNCERTAIN
  - SHUTTLE AS "HUMAN TRANSPORTATION ONLY" BY 1995?
    - PRIVATE TRANSPORT SYSTEMS FOR HIGH ACCELERATION-TOLERANT FREIGHT?

SPACE SCIENCE

- OBVIOUS, EXEMPLARY POSSIBILITIES ONLY
- ULTRA-LONG BASELINE INTERFEROMETRY—INFRARED THROUGH X-RAYS
  - KILOMETER DISTANCES AT GALACTIC CENTER; LUNAR DISTANCES AT UNIVERSE'S EDGE
- "CLASSICAL" ASTRONOMY WITH HUGE SDI APERTURES IN ORBIT
  - REVOLUTIONIZE PLANETARY ASTRONOMY
- SEPARATION AND ANALYSIS OF BIOLOGICAL MACROMOLECULES
  - EXPLOITATION OF MICROGRAVITY AND SUPER-QUALITY VACUUM ENVIRONMENTS
- CREATION, ANALYSIS AND USE OF SMALL, THIN, PURE STRUCTURES ON LARGE SCALES
  - ENTIRELY NEW ARENA OF HUMAN SCIENCE AND TECHNOLOGY

CONCLUSIONS

- SCALE AND NATURE OF NEXT DECADE'S SPACE SCIENCE AND TECHNOLOGY ACTIVITIES WILL BE STRATEGIC DEFENSE-DEPENDENT
  - LAST QUARTER-CENTURY SAW STRATEGIC OFFENSE DOMINANCE VIA SPACE USAGE
  - NEXT QUARTER-CENTURY MAY SEE STRATEGIC DEFENSE DOMINATE THROUGH SPACE EXPLOITATION
  - BASE OF FIRST NON-TERRESTRIAL HUMAN CIVILIZATION MAY BE LAID AS SIDE-EFFECT
- EXISTING ENABLING TECHNOLOGY BASE IS REMARKABLY BROAD
- IMPACT OF COMING DECADE'S SPACE ACTIVITIES ON SCIENCE, TECHNOLOGY AND SURVIVAL OF CIVILIZATION MAY BE GREAT